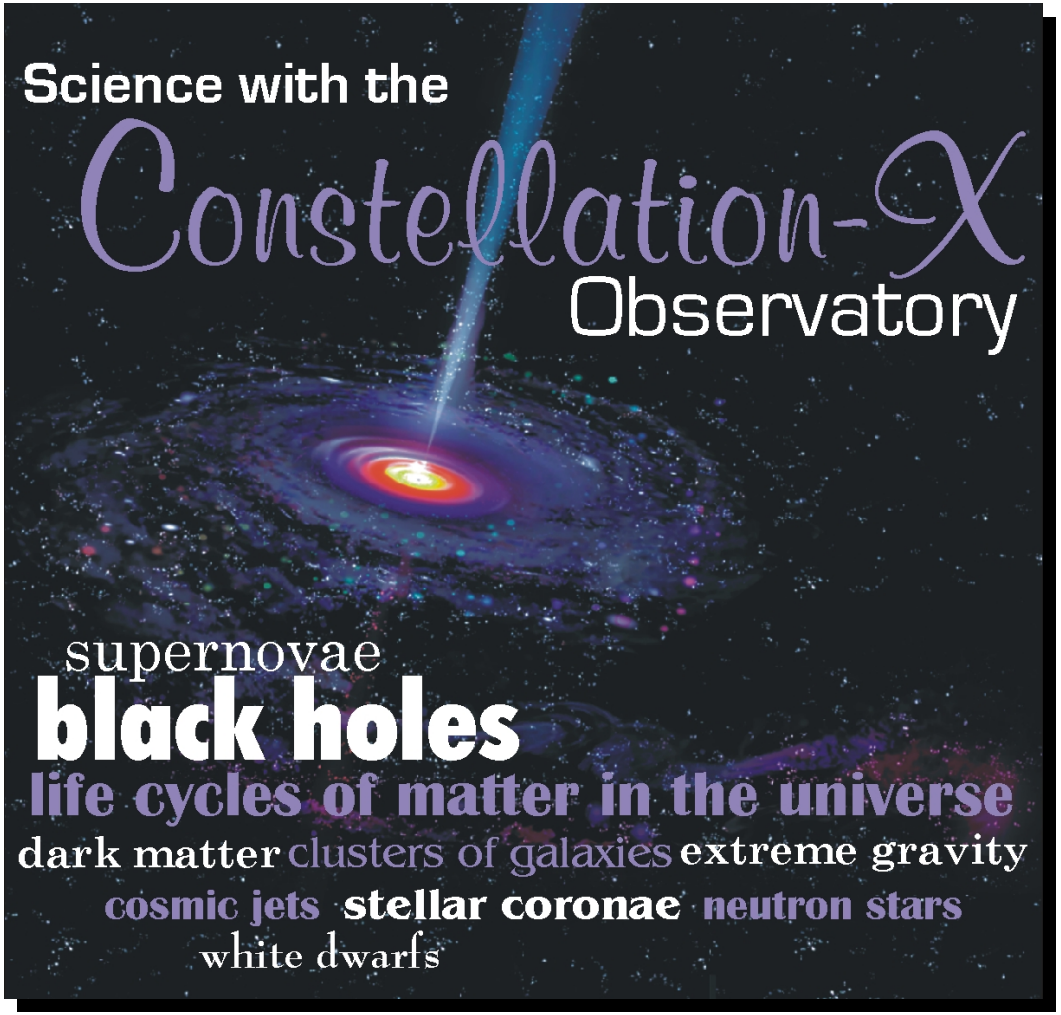
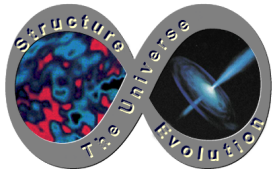
Constellation X-ray Mission



Jean Grady

NASA/GSFC

http://constellation.gsfc.nasa.gov



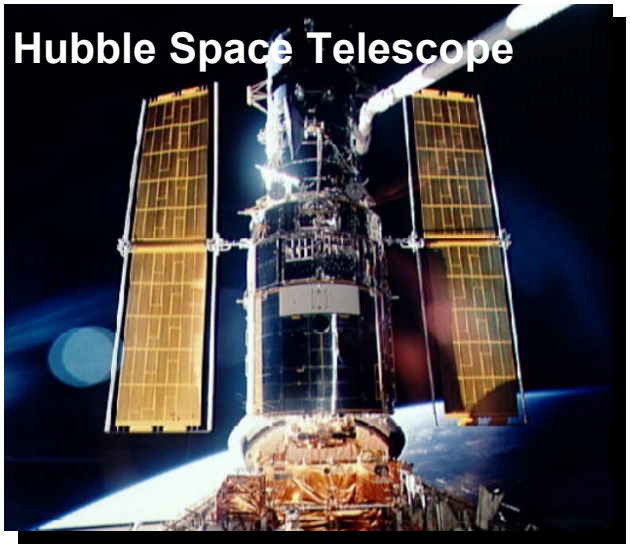
The Constellation X-ray Mission

- **Constellation-X is X-ray astronomy's equivalent of the Keck telescope**
  - Effective area: 15,000 cm^2 at 1 keV
    - 100 times Chandra and XMM for high resolution spectroscopy
  - Spectral resolving power: 3,000 at 6.4 keV
    - 5 times Astro-E calorimeter
  - Band Pass: 0.25 to 40 keV
    - 100 times more sensitive than Rossi XTE at 40 keV

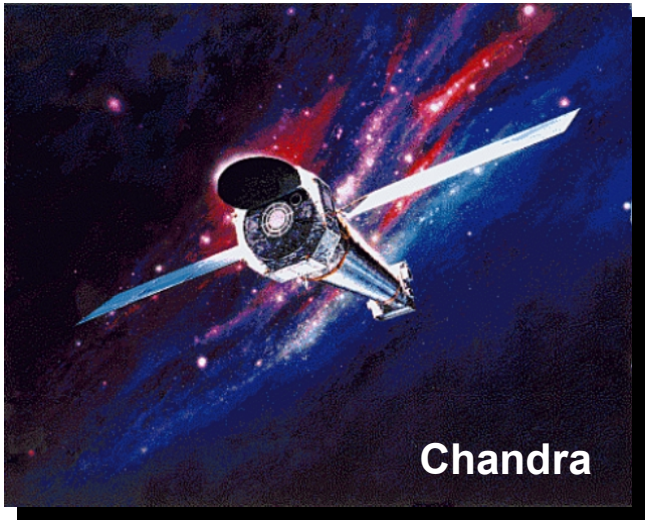
- **Highlights from past year**
  - Revised GSFC/SAO reference mission configuration from six to four spacecraft
    - Results of EELV procurement, consistent with expectations
    - Minimizes launch cost
  - Completed mission configuration studies by Ball and TRW (Cooperative Agreement Notice)
  - Developed independent cost estimates
  - Fabricated light weight 0.5 meter pathfinder shell for X-ray optics from new nickel alloy
  - Demonstrated significant improvement in X-ray calorimeter energy resolution, within factor of two of requirement
  - Achieved higher resolution, lower noise on CdZeTe detectors

X-ray Equivalent of the Keck Telescope

Imaging



0.1 arc sec
40,000 cm^2

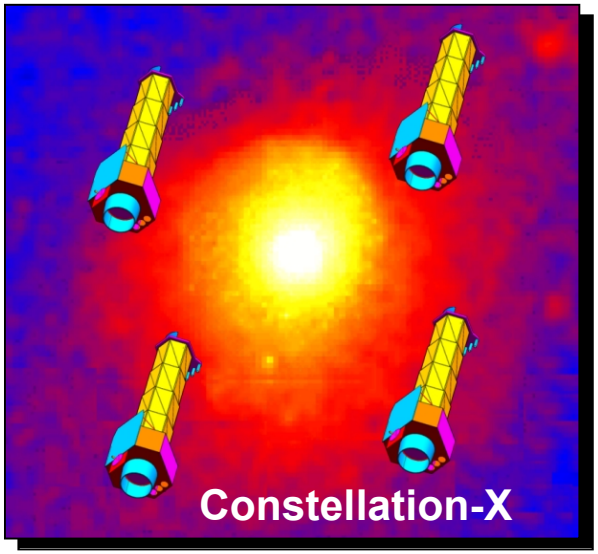


0.6 arc sec
1,000 cm^2
(100 cm^2)*

* effective area at the spectrometer

Spectroscopy

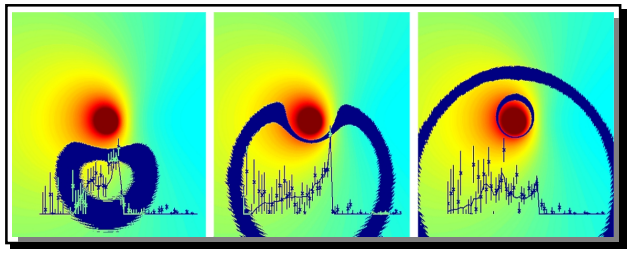
≤1 arc sec
780,000 cm^2



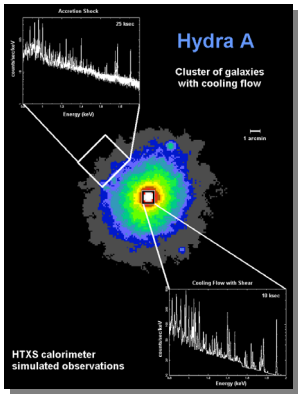
≤15 arc sec
30,000 cm^2
(15,000 cm^2)*

Science Overview

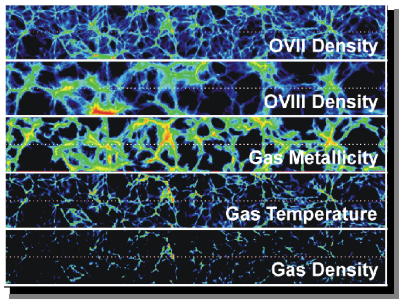
Constellation-X will address key questions to understanding the Universe



- **Can supermassive black holes be used to test General Relativity?**
  - Probe close to event horizons to observe effects of General Relativity in the strong gravity limit
  - Determine black hole spin and mass from broad iron line

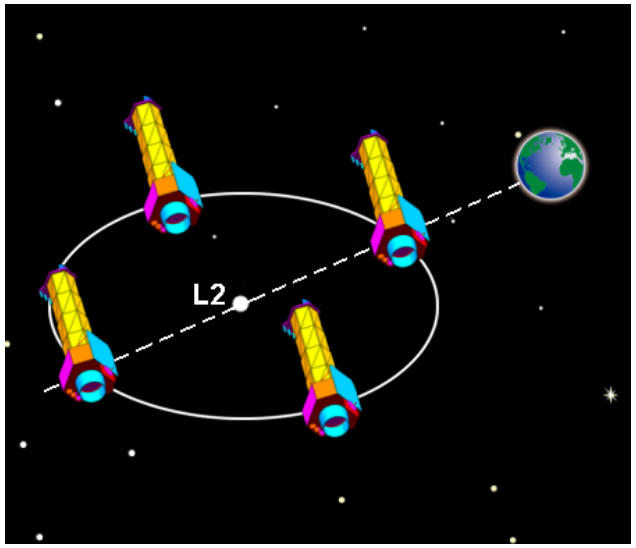


- **When did clusters of galaxies form and how do they evolve?**
  - Determine epoch of cluster formation and trace its evolution
  - Measure elemental abundance of 25 elements including Carbon, Oxygen, Silicon, and Iron
  - Map cluster mergers and cooling flows



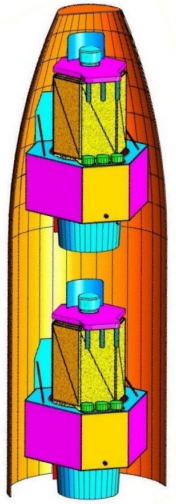
- **Where are the "missing baryons" in the local universe?**
  - Detect baryons in the hot IGM via absorption lines they produce in spectra of background quasars
  - Observe the local Lyman alpha forest

Constellation-X Mission Concept



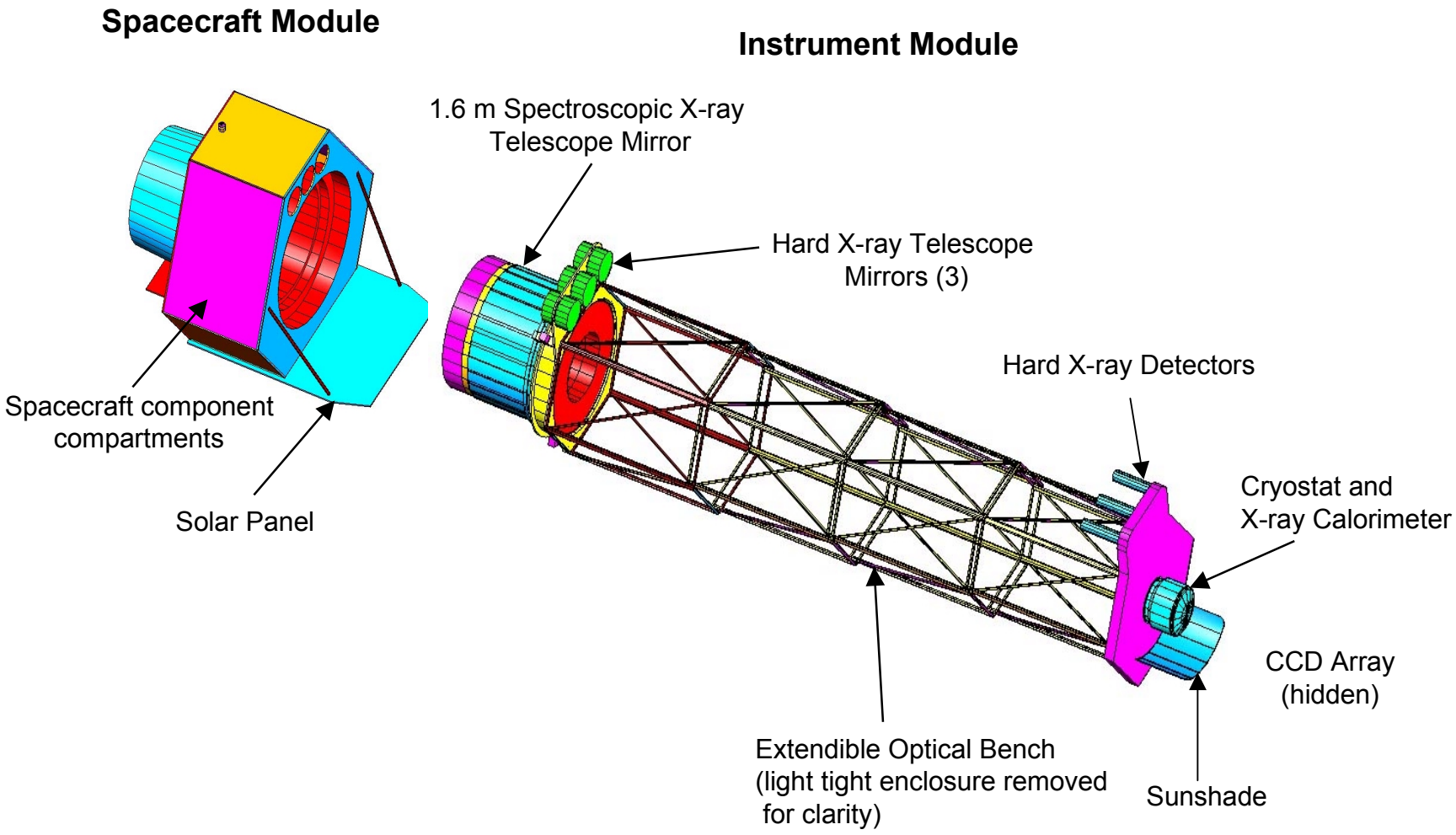
- **A multiple satellite approach**
  - To achieve 30,000 cm^2 aperture on a single satellite requires a Titan-class launch
  - An alternative low-risk approach utilizes a constellation of multiple identical low-cost satellites; each carries a portion of the total effective area
  - Simultaneous viewing and high efficiency facilitated by using libration point orbit

- **Baseline configuration:**
  - Four satellites, launched two at a time on Atlas V or Delta IV
  - Extendible optical bench is used to achieve a focal length of 10 m yet allows two satellites to be packaged on a single launch vehicle
  - Modular design allows:
    - Parallel development and integration of instrument module and spacecraft bus
    - Low cost standard bus architecture and components



Reference Design

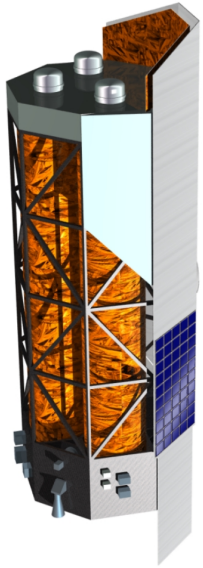
(GSFC/SAO)



CAN Mission Configurations

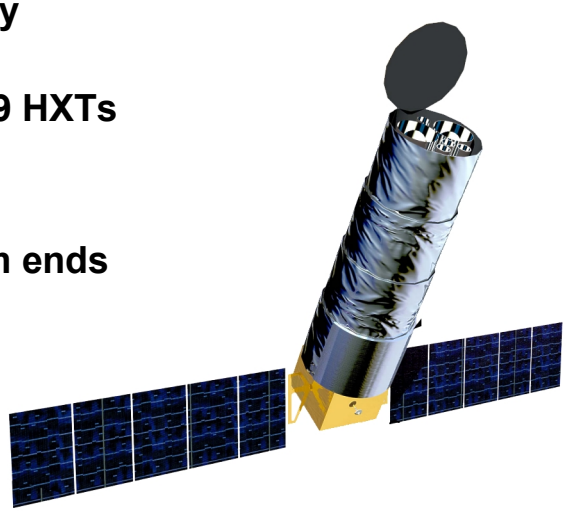
- Successfully completed mission concept studies under Cooperative Agreement Notice (CAN) by Ball and TRW by December 1998.
- Two different technically feasible approaches complement GSFC/SAO approach.
- These studies provided independent cost estimates.

Ball Baseline Configuration



- Two satellites, each fully redundant
- Three 1.3 m SXTs plus 9 HXTs per satellite
- Fixed optical bench
- Separate cold and warm ends to design
- Requires two EELVs

TRW Baseline Configuration



- Three satellites
- Two 1.3 m SXT plus four HXTs per satellite
- Extendible optical bench
- Simple s/c bus based on existing designs
- Requires three EELVs

Constellation-X Requirements Flow Down

Science Goals

- Parameters of Supermassive Black Holes
- Elemental Abundances and Enrichment throughout the Universe
- Plasma Diagnostics from Stars to Clusters

Measurement Capabilities

Minimum effective area:
SXT
15,000 cm² at 1 keV
6,000 cm² at 6.4keV
HXT
1,500 cm² at 40 keV

System Angular Resolution and FOV
SXT
15" HPD
FOV >2.5'
HXT
1' HPD
FOV >8'

Minimum spectral resolving power (E/DE):
SXT
300 from 0.25 to 6.0 keV
3000 at 6 keV
HXT
>10 at 40 keV

Band Pass:
SXT
0.25 to 10 keV
HXT
6 kev to 40 keV

Engineering Implications

Minimum Effective Area:
- Light Weight Optics (<250 kg.)
- Extendible Optical Bench (8-10 m)

System Angular Resolution and FOV:
- Tight tolerances on telescope figure, surface finish, alignment
- ±1 ºC temp. control on mirror assembly
- Requires ≥ 30 x 30 array for microcalorimeter (pixels ~5")
- Cryocooler requirements driven by array size and readout electronics

Resolving Power:
- Dispersive *and* non-dispersive capability to cover SXT band
- Dispersive performance tied to telescope resolution

Band Pass:
- 2 types of telescopes needed to cover energy range

Key Technologies

High Throughput Optics
- High performance replicated shells and segments
- coatings and layers
- High strength/mass materials for optical surfaces

High Spectral Resolution
- 2 eV microcalorimeter arrays
- Coolers
- Lightweight gratings
- CCD arrays extending to 0.25 keV

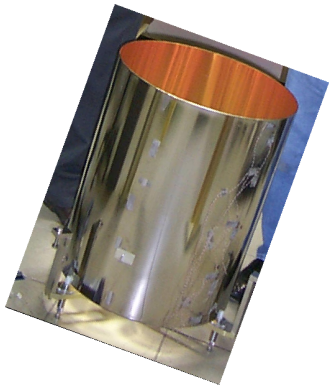
Broad Bandpass
- Multilayer optics
- CdZnTe detectors

Extendible Optical Bench
- Stable (vs. time and temp.)
- High strength/low weight materials

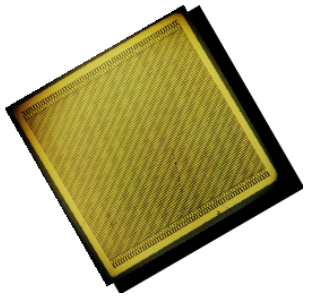
Constellation-X Technology

Approach

- **Extension of demonstrated technology**
- **Parallel path technology development with defined selection milestones**
- **Synergism within program activities, e.g., SXT and HXT optics**
- **Leverages other technology investments:**
  - Cross-enterprise technology, e.g., Cryocoolers
  - SBIR, e.g., optics
  - SR&T, e.g., CdZeTe detectors

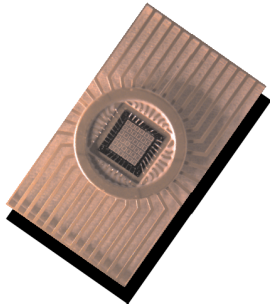


Lightweight X-ray Optics

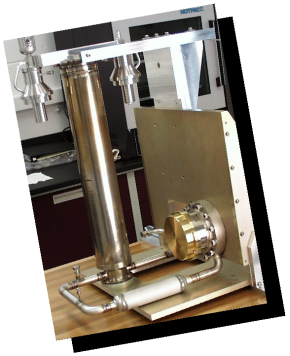


CdZnTe Arrays

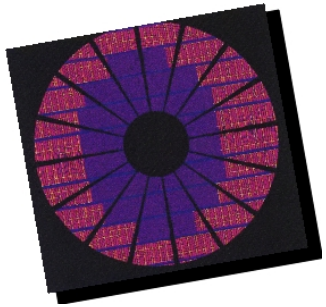
Multilayer Coatings



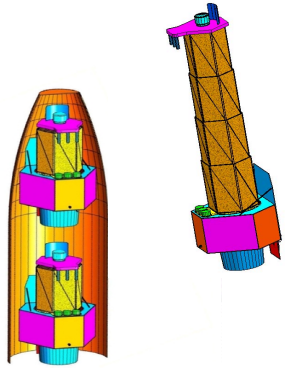
X-ray Calorimeters



Cryocoolers

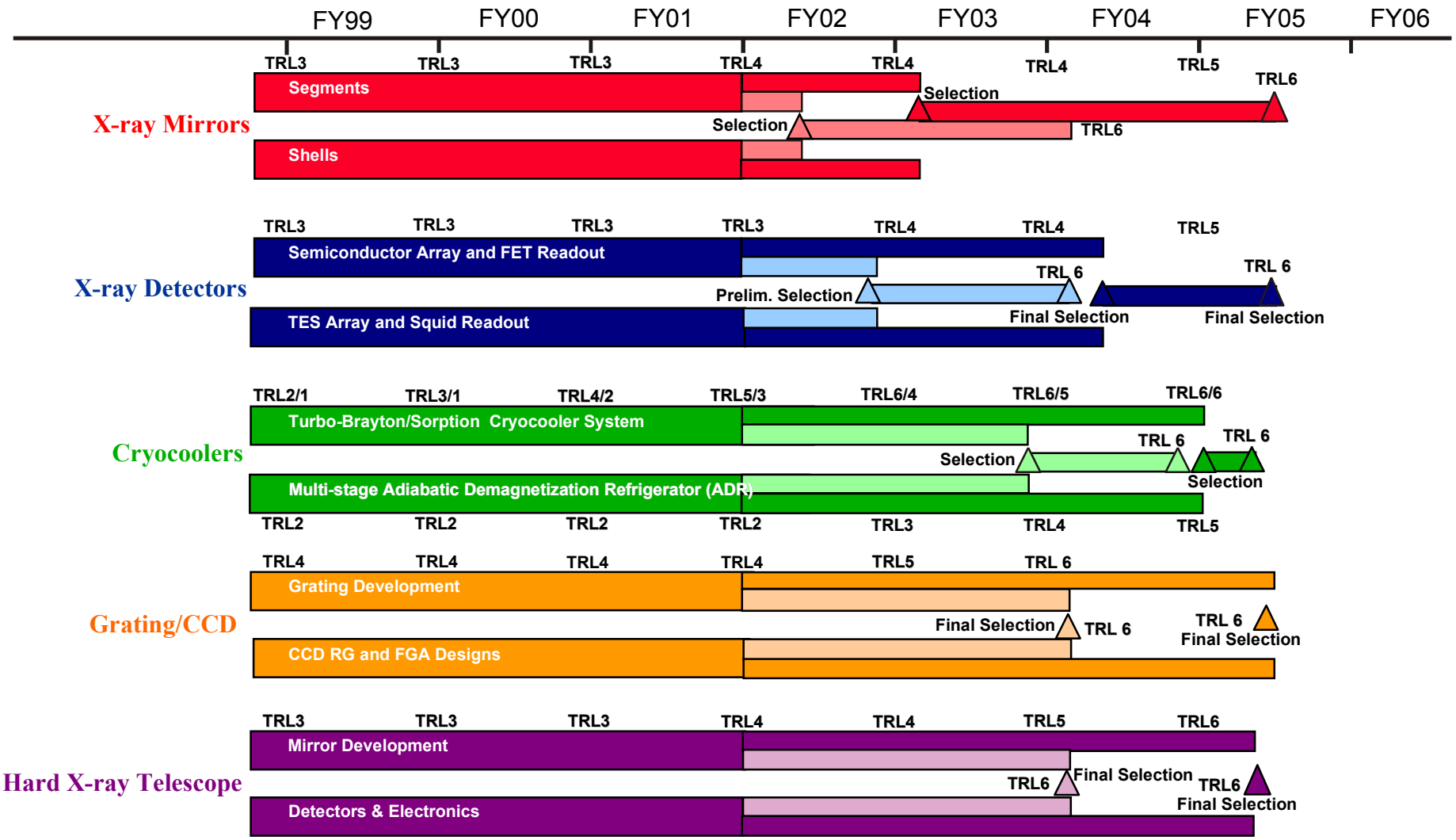


CCD/Gratings



Deployable Structures

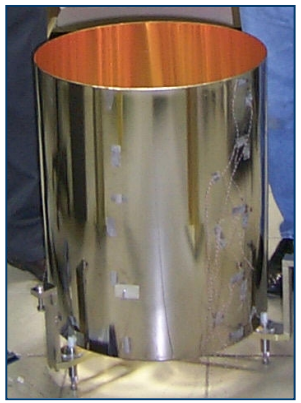
The Constellation-X Technology Roadmap



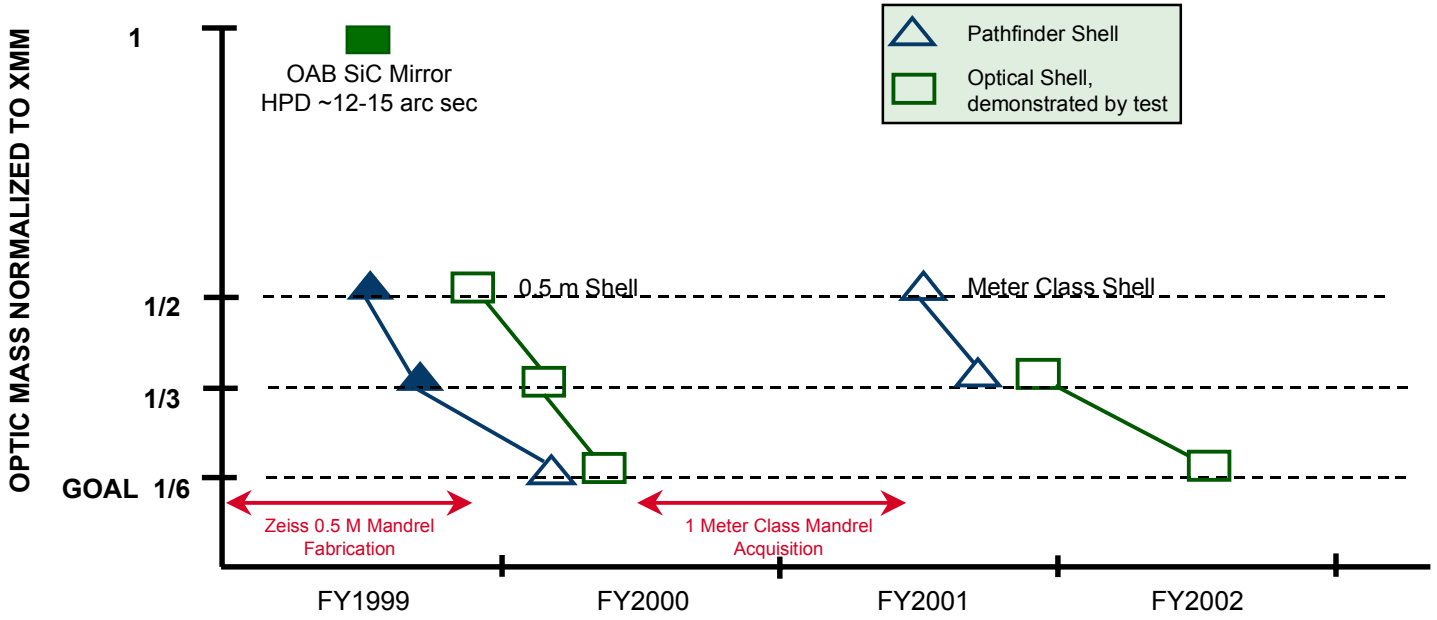
Solid Colored	▲	Technology development plan for current in-guide budget; meets FY2007 New Start
Shaded Light	▲	Plan requires augmentation to meet 2005 new start

SXT Replicated Shell X-ray Mirrors

- **Goal is to show feasibility of 1.6m replicated shell mirror with normalized weight 1/6 of XMM mirror and Half Power Diameter (HPD) of <10 arc sec**



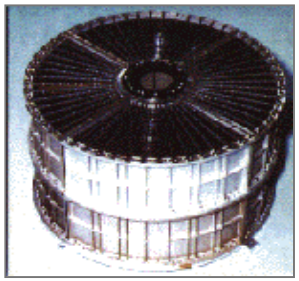
0.5m Shell

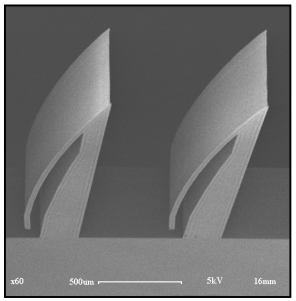


- **Progress**
  - Developed infrastructure for manufacturing and metrology of large X-ray optics
  - Developed high performance electro-formed nickel alloy
    - Micro-yield order of magnitude higher than pure nickel
    - Fabricated 0.5 m pathfinder shell and demonstrated shell separation
    - 0.5 m optic for X-ray testing in process
  - Silicon Carbide (SiC)
    - OAB manufactured SiC mirror with HPD ~12-15 arc sec
- **Partnership: MSFC/SAO/OAB**

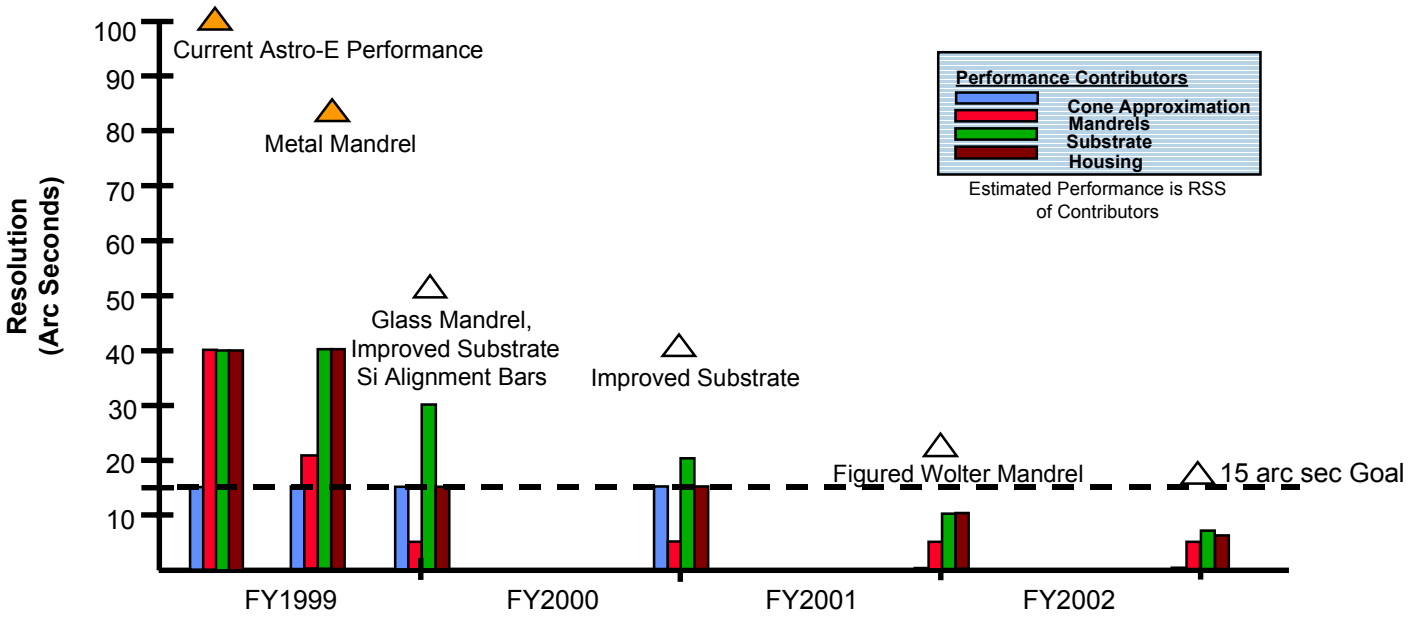
SXT Segmented X-ray Mirrors

- **Goal is to show feasibility of a 1.6 m replicated segment mirror having a normalized weight of 1/6 XMM and a system HPD of 15 arc sec**
  - Segmented approach already meets weight requirement





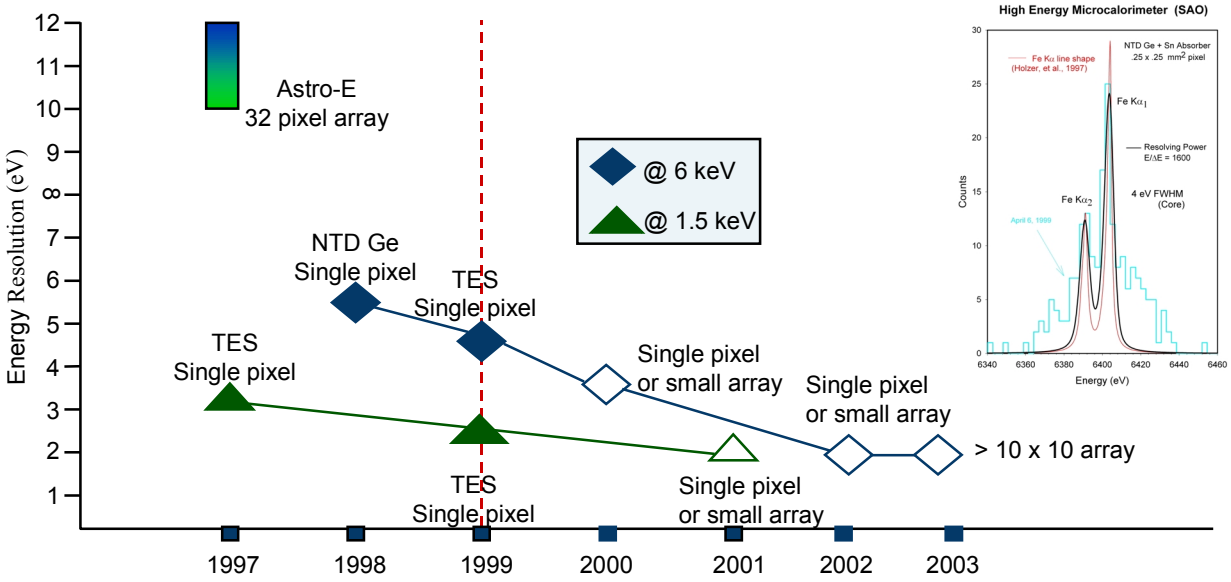
Etched Silicon Alignment Bar

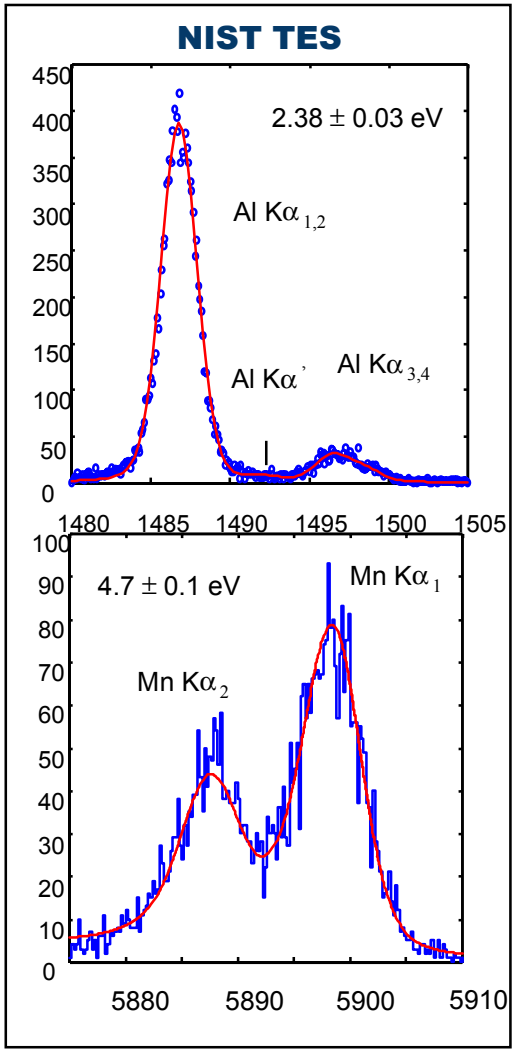


- **Progress**
  - Metal mandrel improved mandrel figure by factor of 2 over Astro-E
  - Glass mandrel, to be delivered June 1999, will improve mandrel figure by an additional factor of 4
  - Designed and fabricated ultra-precise alignment bars using silicon etching technology
- **Partnership: GSFC/MIT/SAO/RJHS**

X-ray Calorimeters

- **Needed: 2 eV FWHM from 1 to 6.9 keV at 1000 counts/s/pixel in 30 x 30 array**
- **Parallel Approach: TES and NTD/Ge Calorimeters**

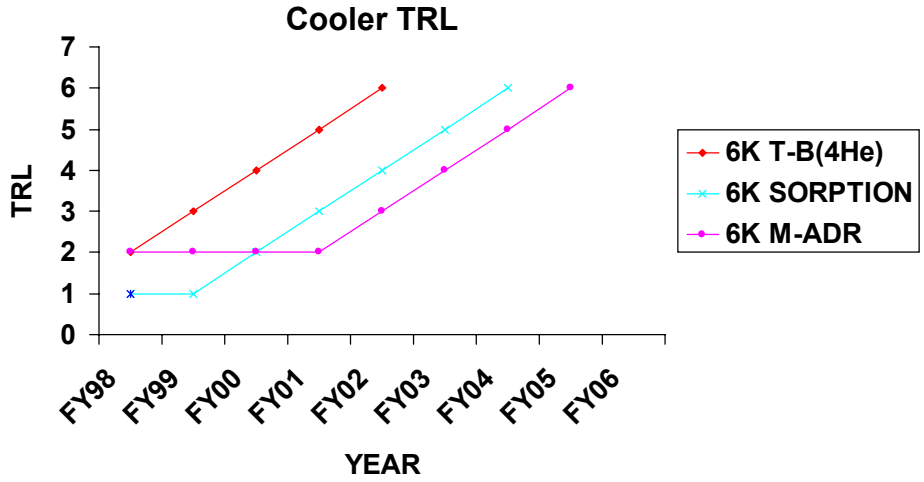


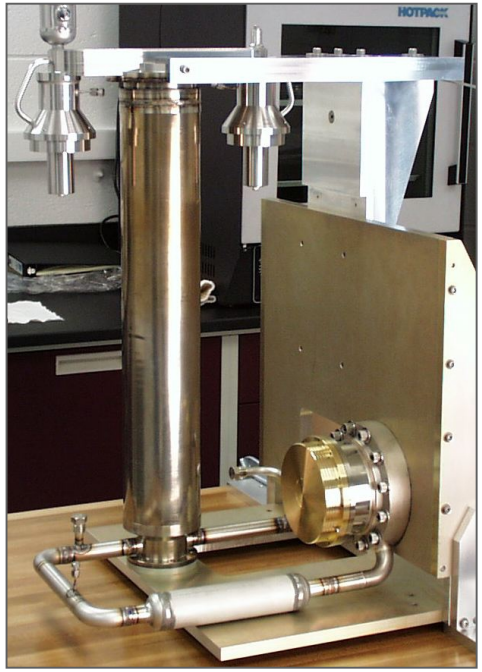


- **Progress:**
  - Achieved 2.4 eV at 1.5 keV and 4.7 eV at 6 keV!
  - Identified robust materials for TES thermometer
  - Fabricated and analyzed pop-up Si array structures for TES
  - Demonstrated technique for cantilevering TES absorbers
  - Manufactured a 16-element NTD/Ge array
  - Demonstrated techniques for multiplexing
- **Partnership: GSFC/NIST/SAO/UW/LLNL/Stanford**

Cooling Systems for X-ray Calorimeter

- **Requirement: Long life cooling systems that provide 40 - 65 mK to calorimeter**
- **Parallel Approach: Turbo-Brayton or Sorption cooler to 4 - 8 K with multi-stage ADR**
- **Progress:**
  - Turbo-Brayton
    - 70 K cooler was successfully flown on HOST Shuttle mission
    - 65K cooler completed 3 year endurance test
    - Completed cold bearing tests on 35 K cooler; 10K tests planned for 1999
    - 4-10K breadboard being fabricated for test in late1999
  - Sorption cooler
    - 6K breadboard planned for 2002
- **Require funding for multi-stage ADR development**





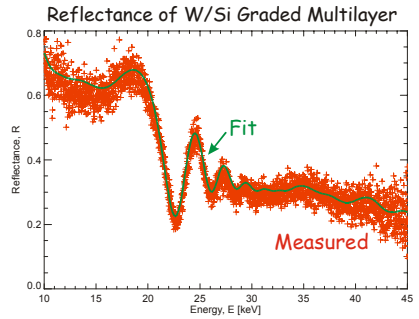
HOST Cooler

- **Partnership: GSFC/JPL/Creare**

Hard X-ray Telescope

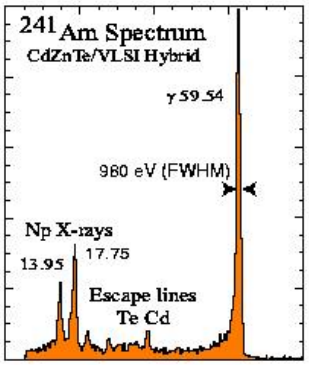
HXT Optics

- **Requirements: High reflectivity from ≤ 6 to ≥40 keV with 1 arc min. HPD over an 8 arc min. FOV**
- **Completed opto-mechanical breadboard of thermally-formed glass microsheet optics**
  - 40 arc sec HPD figure for mounted shells
  - High-throughput segmented optic mounting technique
- **Multi-layer development**
  - Measured reflectance corresponding to 2.5A interface widths for complex 300 layer W/Si coating
  - Demonstrated stability of Pt/C multilayers

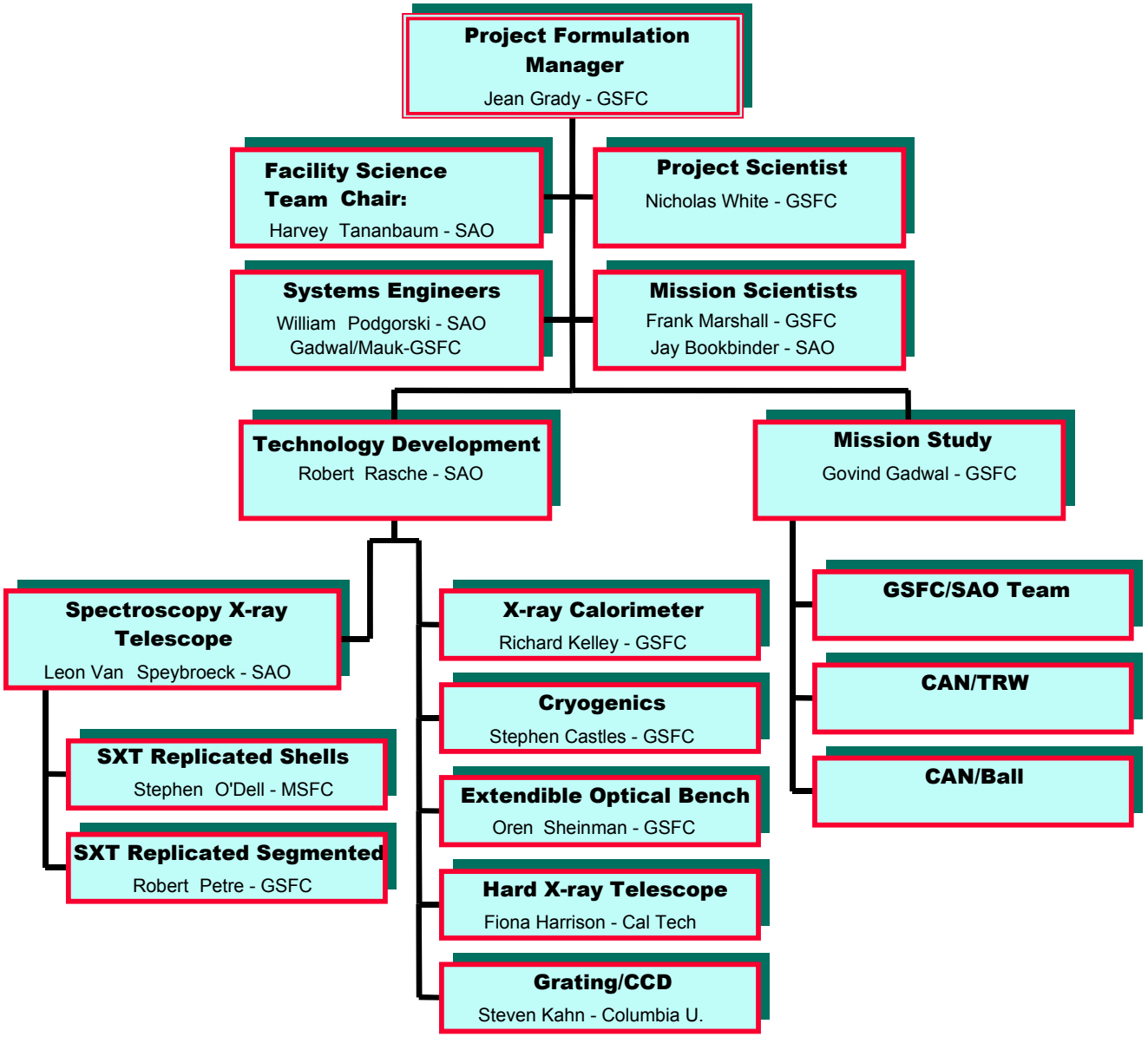


Detectors

- **Requirements: Low threshold (≤6 keV), large format (~1 in. x 1 in.) with high QE**
- **Demonstrated new, custom, low-noise ASIC/CdZnTe detector**
  - 980 eV FWHM (60 keV) - factor of 3 improvement over any existing pixel detector
  - 2 keV threshold - factor of 5 improvement over any existing pixel detector
  - Required improvements: reduce pixel size 20%, reduce noise factor 2
- **Successful selection of near-perfect 1 in. x 1 in. CdZnTe sensors**
  - Demonstrated high yield from commercial product using new characterization and screening facility
- **Partnership: CalTech/GSFC/Columbia U./MSFC/Harvard/SAO/NW/NRL**

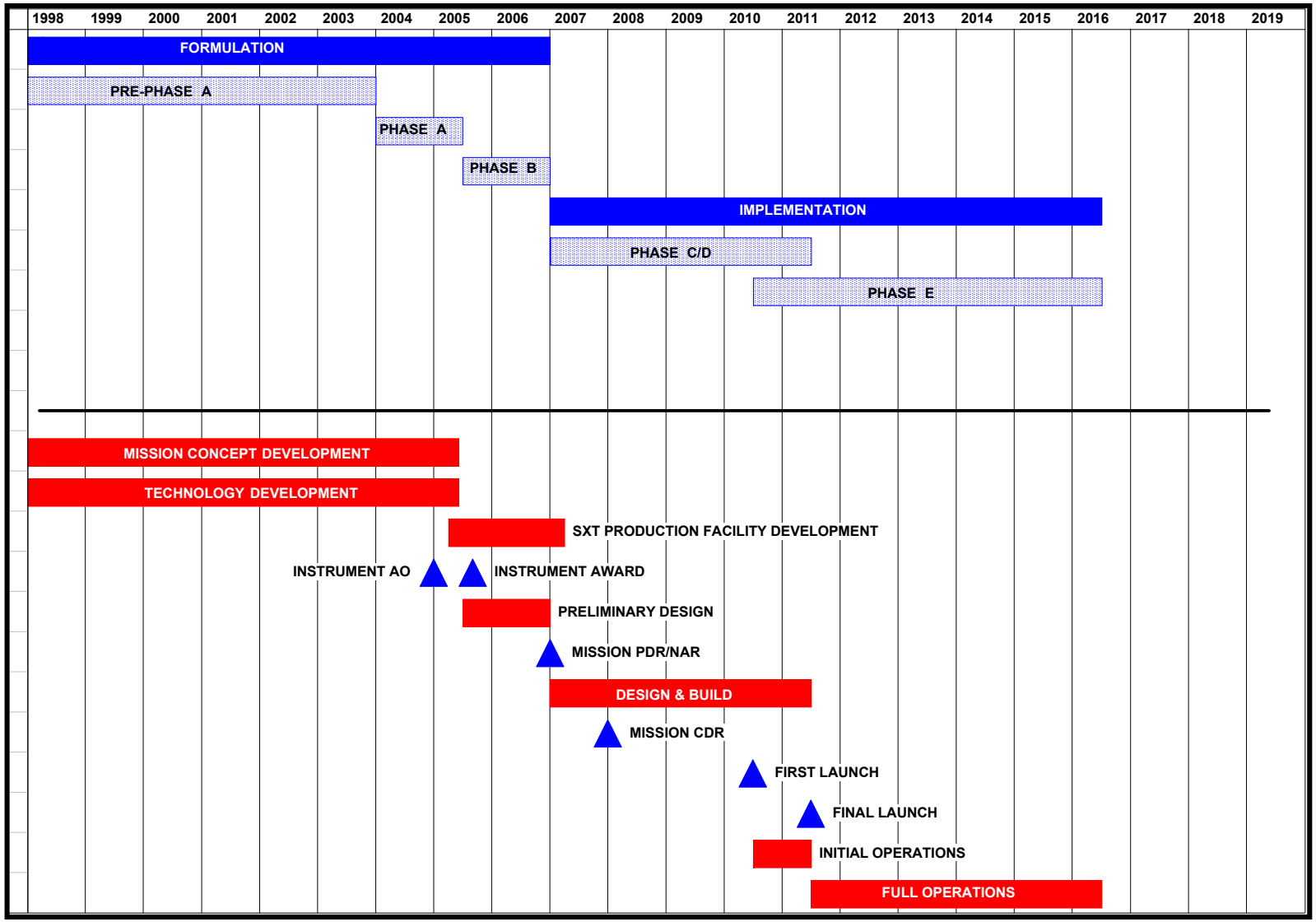


Organization

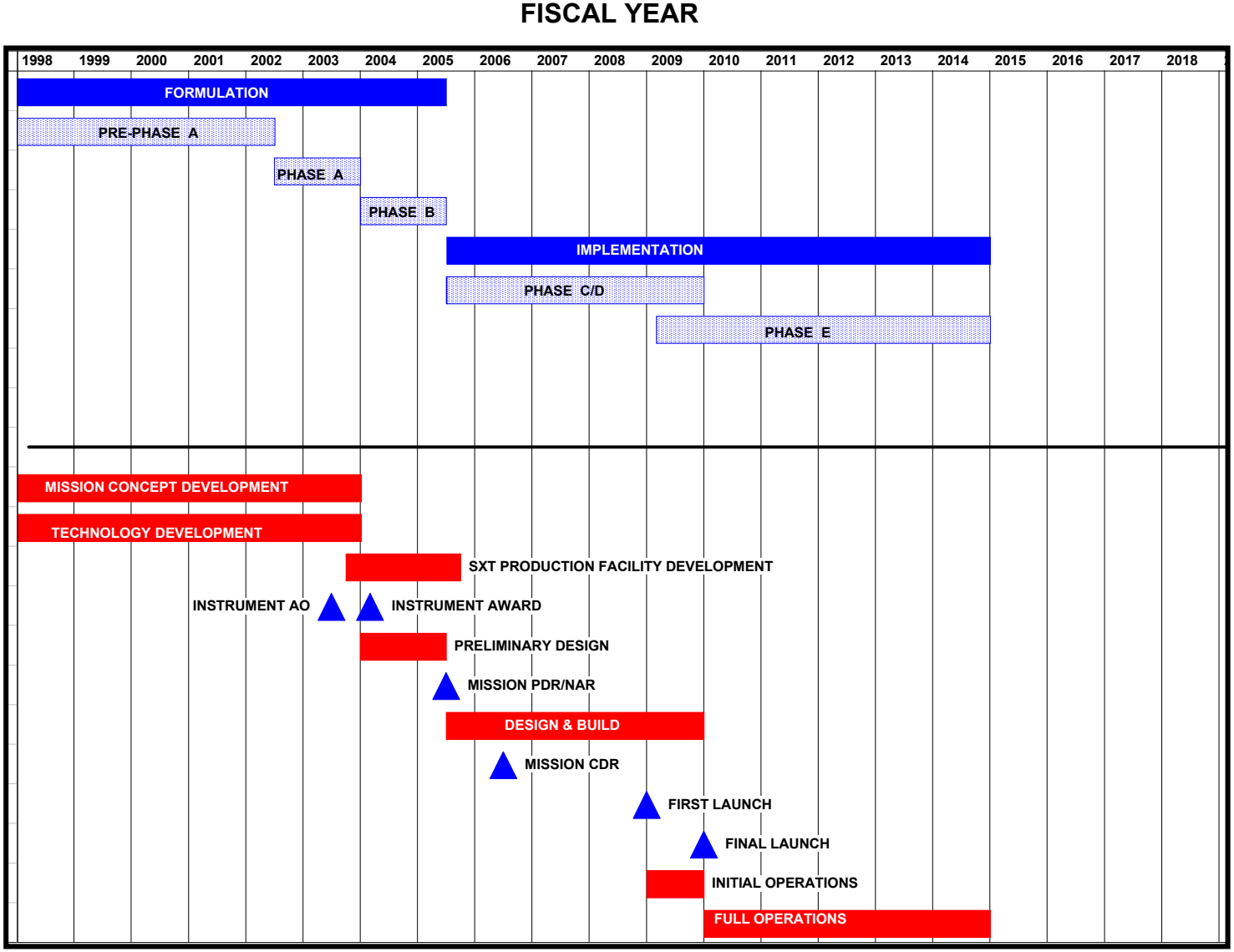


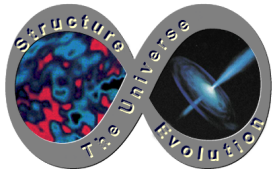
Top Level Schedule

Consistent with Re-phased Guidelines



Top Level Schedule for 2005 New Start



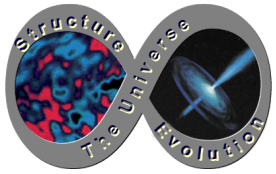


Issues

- **Constellation-X is the only mission in the 1997 OSS Strategic Plan not adequately funded to support a new start by 2004**

- **Need to establish earlier launch date to:**
  - Provide for timely transition and continuity in high quality X-ray observations
  - Provide overlap between Constellation-X and Chandra for cross calibration and science synergy (similar to Keck and Hubble Space Telescope)

- **Need to increase current funding guidelines to:**
  - Support technology efforts already selected via peer review in April 1998
  - Maintain momentum and skill base for technology development and mission studies
  - Capitalize on Code S technology investments in Chandra, Astro-E and XMM



The Outlook for Constellation-X

- **One-year outlook (Spring 2000)**
  - Complete 0.5 m optic at required weight (1/6 mass normalized to XMM)
  - Continue to improve X-ray calorimeter resolution
  - Continue development of mission configuration; define error and alignment budgets

- **Five-year outlook (Spring 2004)**
  - With current in-guide budget:
    - Conducting Phase A mission studies with two industry partners
    - Technology development in progress
    - Drafting instrument AO in preparation for release
    - About to begin development of SXT production facility
  - With requested augmentation:
    - Technology development is complete
    - Instrument AO has been released and the instruments have been selected
    - Mission Prime contractor has been selected
    - Preliminary design is well under way
    - Mission PDR and NAR will occur within the next year